NAFO Sci. Coun. Studies, 21: 19–41

Oceanographic Conditions During the Annual Autumn Groundfish Survey in NAFO Divisions 2J and 3KL

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Abstract

Analysis of the water temperature data collected during the annual autumn groundfish survey in NAFO Div. 2J and 3KL indicated that the surface temperature over the entire area was between 1.0° to 2.0°C below the long-term mean during the month of November 1992 and about 1.0° to 3.0°C below the 1991 values for the same time period. The horizontal temperature field at the 100 m depth showed a much more extensive cold intermediate layer (CIL) over the northeast Newfoundland shelf in both 1991 and 1992 compared to the long-term mean. Off Cape Bonavista the cross-sectional area of the autumn CIL was slightly below the 1980–90 mean in 1991 and slightly greater in 1992 with a much colder upper layer compared to 1991.

At Station 27 temperature anomalies were slightly positive in the upper layer in 1991 and slightly negative in 1992, and strongly negative in both years at mid-depths. At the bottom, the autumn temperature anomaly was approximately -0.5°C in 1991, but had warmed to -0.2°C in 1992.

The analysis of the autumn data also showed bottom temperatures were up to -1.0°C below normal (based on a 1980 to 1990 mean) over the Grand Bank and the northeast Newfoundland shelf in 1992. The negative temperature anomalies were mainly restricted to Div. 3L in 1991 with maximum amplitudes of about -1.0°C. Analysis of bottom temperature time series since 1977 by strata showed negative anomalies during 1984/85 and 1991/92 for some but not all strata.

In general the strong negative temperature anomalies experienced during the spring and summer of 1991 had moderated by the autumn of 1991 over most areas. In 1992 the spring and summer water temperatures were near normal but large negative anomalies had returned by the autumn of 1992.

Key words: Newfoundland area, oceanography, surveys, temperature

Introduction

The very cold air temperatures experienced during the winter of 1990 and 1991 resulted in abnormal ice coverage during the spring of 1991. This gave rise to large negative temperature anomalies during late spring and summer (Drinkwater *et al*., MS 1992. Narayanan *et al*., MS 1992). By the autumn of 1991 water temperatures had returned to near normal conditions over most of the area and by the spring of 1992 water temperatures were again at near normal levels. The cold air temperatures (up to -6.0°C below normal, Findlay, 1992) experienced over Atlantic Canada during late-spring and summer of 1992 again may have contributed to large negative temperature anomalies over most of the water column by November 1992.

This paper presents an overview of the environmental conditions in the Northwest Atlantic based on temperature data collected mainly from the annual autumn groundfish surveys in NAFO Div. 2J and 3KL since 1980. Data from other sources as well as all available historical data for the area are included in the analysis. The horizontal, vertical and bottom temperature field for the autumn (late-October to mid-December) of 1991 and 1992 are compared to the long-term, and the 1980 to 1990 means.

Materials and Methods

Data sources and analysis

Water temperature data for NAFO Div. 2J and 3KL were available from archives at the Marine Environmental Data Service (MEDS) in Ottawa and the Northwest Atlantic Fisheries Center (NAFC) in St. John's Newfoundland. During the autumn period since 1977 in Div. 2J, and since 1981 in Div. 2J and 3KL the bulk of these data were collected during the stratified-random groundfish surveys using XBTs. Since the autumn of 1989 most of the water temperatures were measured using trawl-mounted Seabird 19 CTD systems. The extraction of the bottom temperature has also changed from a single measurement at the bottom of the XBT trace (usually at the end of the tow) to a 10 to 20 min. horizontal average along the center portion of the tow. The temperature measurements made during the deployment of the trawl were used together with other available data to determine the temperature field over the water column.

Horizontal maps of the average temperature at standard depths were produced from all available data from 1910 to 1990 for a particular month over a region of interest. The actual isotherms were then derived from unweighted averages of all temperature profiles within a square grid with spacing of 0.25 degrees. The data were then quality controlled and linearly interpolated to the standard depth of interest. No attempts were made to adjust the data for possible temporal or spatial aliasing arising from this averaging procedure. Some temporal aliasing was probably present in the analysis given the wide time interval over which the autumn survey was conducted plus the fact that this is a period when rapid cooling of the upper water column is taking place.

Horizontal bottom temperature maps were produced by taking all near-bottom temperature values for the annual autumn groundfish survey in Div. 2J and 3KL. For this purpose all data collected on several groundfish cruises from late-October to mid-December were assumed to be representative of the mean autumn temperature. The average bottom temperature maps were generated by averaging all data within a stratum for the period 1980 to 1990 inclusive, yearly anomalies were then determined from this average. Time series of temperature and anomalies were produced from 1977 to 1992 for selected strata. Again data from all groundfish trawl sets within a particular stratum were averaged for each year.

Vertical cross-sections of the temperature structure were contoured by taking all observations within 40 minutes of latitude of the standard NAFO Bonavista transect between the middle of October and the middle of December. The observations were then assumed to lie on a line joining the endpoints of the standard transect. The data were then interpolated to 5.0 m depths intervals and averaged into 5.0 km bins along the line. Again the data were not adjusted to account for spatial or temporal aliasing.

Results and Discussion

Horizontal temperature field

Figure 1A shows the mean surface temperature field for November derived from all available data as described above. The mean surface temperature ranged from 1° to 3°C shoreward off the shelf break in Div. 2J and 3K, and from 3° to 6°C in Div. 3L (isotherms are -1, 0, 1, 2, 4, 6, etc °C, bathymetry lines are 300 and 1 000 m). Figure 1B and 1C show the surface temperature determined from all available data for November 1991 and 1992. The surface temperature in November 1991 ranged from approximately 1° to 4°C in Div. 2J and 3K, and from 4° to 8°C in Div. 3L, somewhat higher than the average. In November 1992 the surface temperature ranged from 1° to 2°C in Div. 2J and 3K, and from 2° to 4°C in Div. 3L, about 1° to 4°C below the 1991 values and 1° to 2°C below normal.

Figure 2 shows the November average and the 1991 and 1992 temperature at a depth of 100 m at about the center of the cold intermediate layer (CIL). On average water at 0.0°C covered the entire Grand Bank and part of the northeast Newfoundland shelf. In 1991 and 1992 the 0.0°C water was much more extensive over the northeast Newfoundland shelf, with the largest anomaly of about -1.0° to -2.0°C in 1992. This was in contrast to the near normal upper layer temperature in 1991.

Vertical temperature field

A dominant feature of the temperature structure along the east coast of Newfoundland on the continental shelves is the CIL (Petrie *et al.*, 1988). The CIL is most apparent in the summer when spring ice melt and seasonal heating has increased the stratification in the upper layers to a point when heat transfer to the lower layers is inhibited. The result is a cold layer of water with temperatures ranging from -1.5° to 0.0°C sandwiched between the warm upper layer and warmer water near the bottom.

Figure 3A shows the average temperature for the transect off Cape Bonavista during the approximate time period of the annual autumn groundfish survey from 1981 to 1990. This transect spans the northern section of Div. 3L and the southern portion of Div. 3K. The seasonal warm upper layer had not completely cooled down, so the summer-like structure of the CIL was still present with an average cross-sectional area of about 23.5 km^2. The temperature structure across the northeast Newfoundland shelf in the bottom layer was very similar to summer conditions. For example the anchor position of the 2.0°C isotherm was situated at about

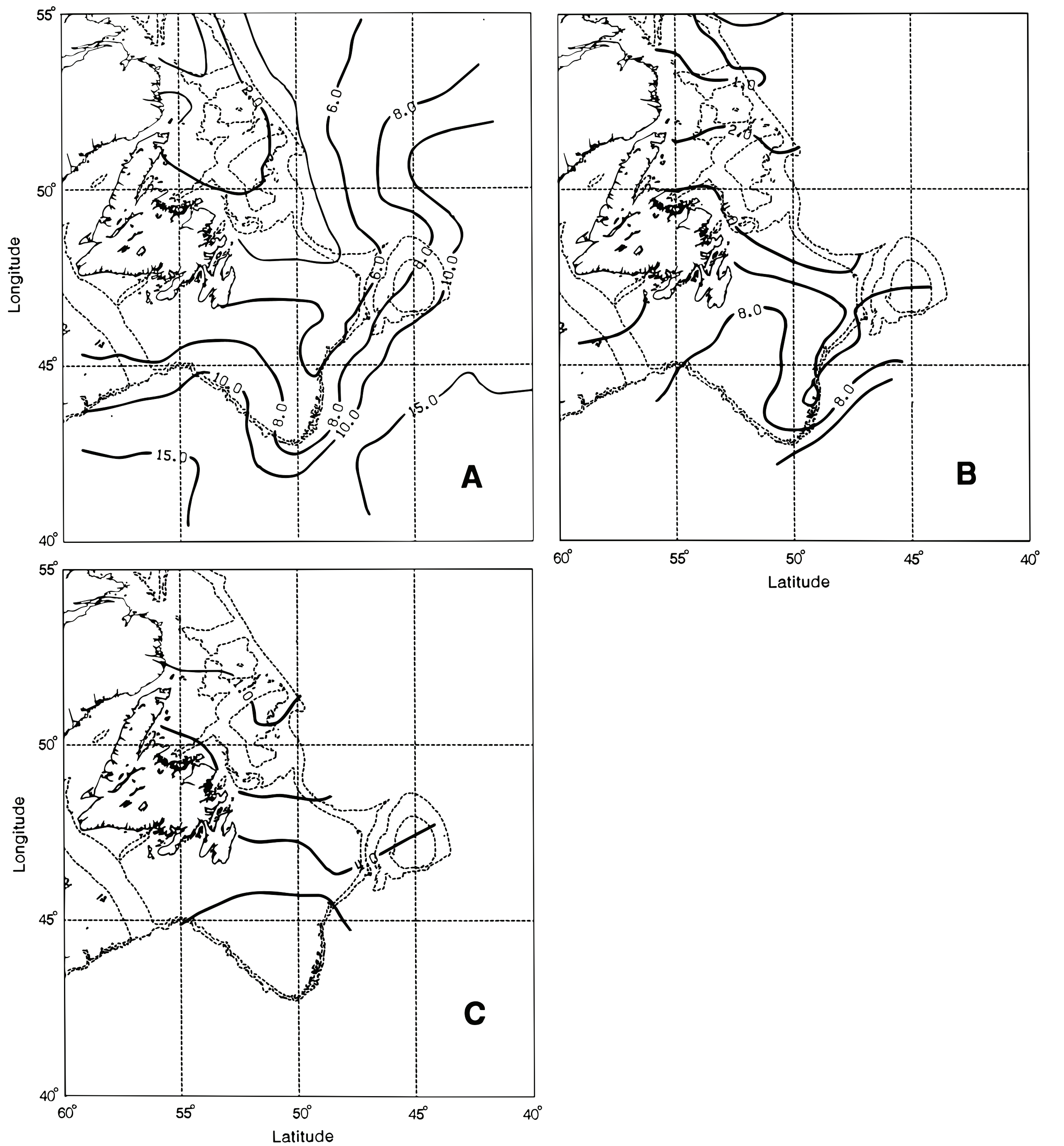


Fig. 1. The average surface temperature isotherms for November, (**A**) from all available data, (**B**) surface temperature isotherms for November 1991, and (**C**) November 1992.

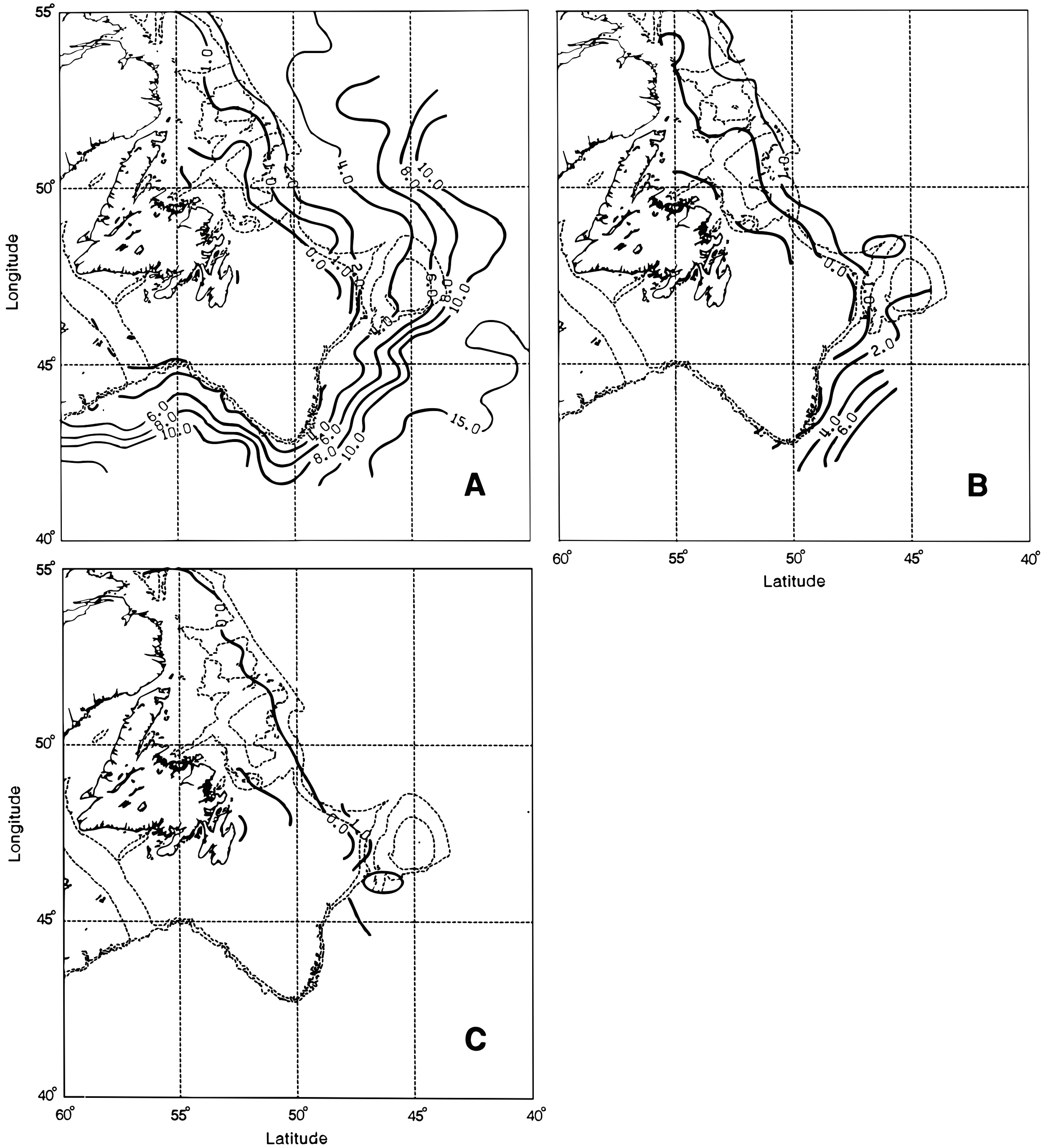


Fig. 2. The average temperature isotherms at 100 m for November, (**A**) from all available data, (**B**) temperature isotherms at 100 m for November 1991, and (**C**) November 1992.

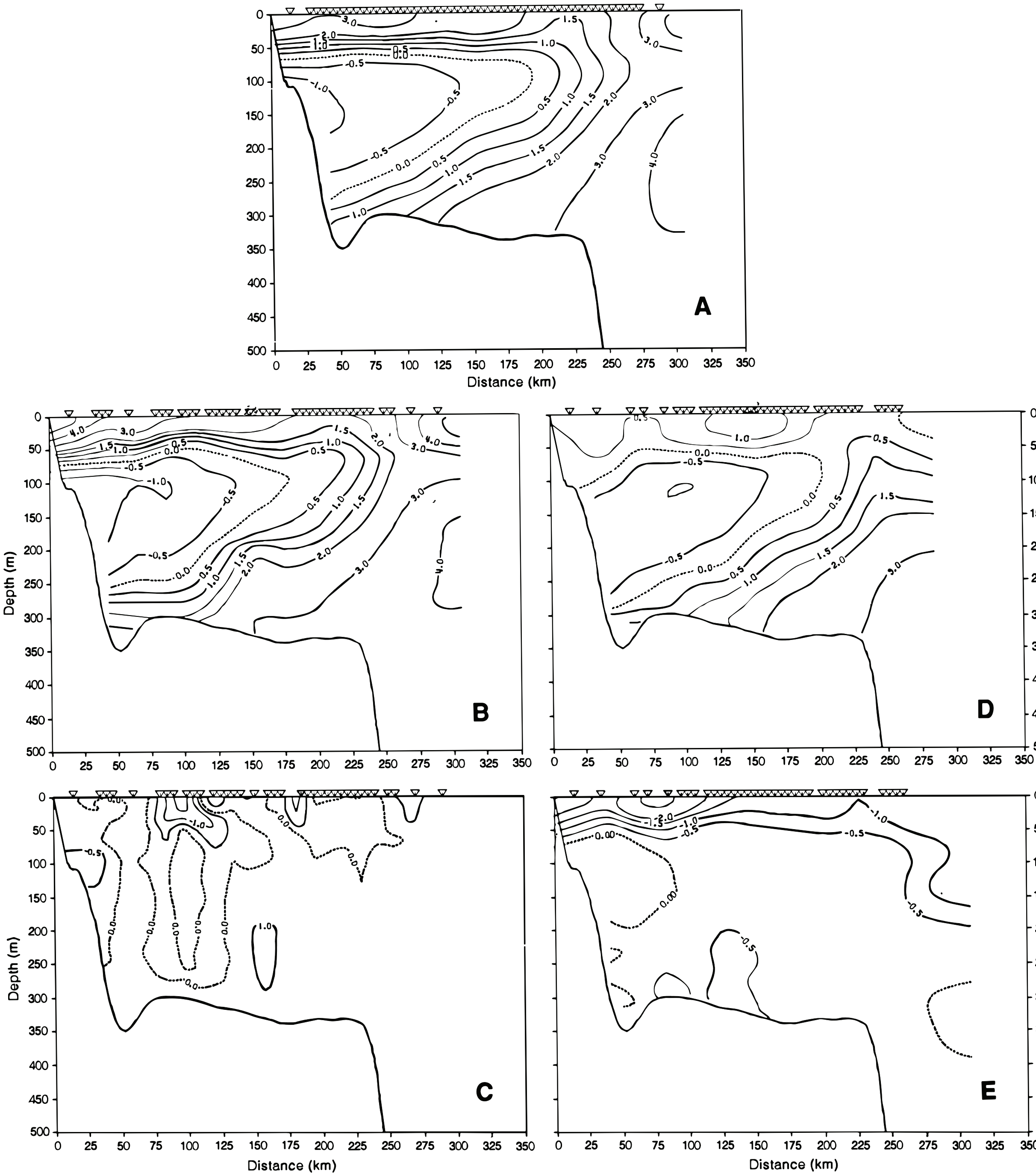


Fig. 3. (**A**) The 1981 to 1990 autumn average temperature isotherms, (**B**) the 1991 autumn temperature and (**C**) anomaly, (**D**) the 1992 autumn temperature and (**E**) anomaly, for the Cape Bonavista transect.

125 km offshore and the 3.0°C isotherm was located near the edge of the shelf, about the same as the average summer positions. Figure 3(B–E) shows the temperatures and anomalies along the Bonavista transect for the autumn of 1991 and 1992. The temperature anomaly was based on an autumn mean from 1981 to 1990. The cross-sectional areas of the CIL less than 0.0°C were about 22 and 27 km^2, respectively. The figures show a much colder surface layer in 1992 compared to 1991, and the mean. The largest anomaly (-0.5° to -2.0°C) occurred during 1992 at water depths less than 50 m. The 1981 to

1992 time series of the CIL area for the summer (July–August) and autumn (late-October to mid-December) is shown in Fig. 4. The autumn CIL area showed similar trends as in the summer, however the average area had decreased from 33.0 km^2 during the summer to 23.5 km^2 in the autumn as a result of summer heating and vertical mixing over the water column.

Station 27 time series

Time series of the vertical temperature structure and anomalies at Station 27 off St. John's for the autumn of 1991 and 1992 are shown in Fig. 5. The anomalies were calculated from the mean of

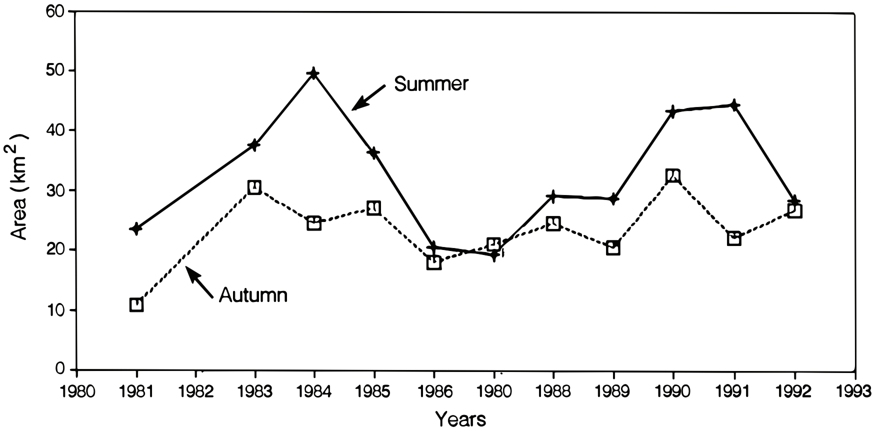


Fig. 4. Time series of CIL cross-sectional area less than 0.0°C during summer and autumn for the Cape Bonavista transect.

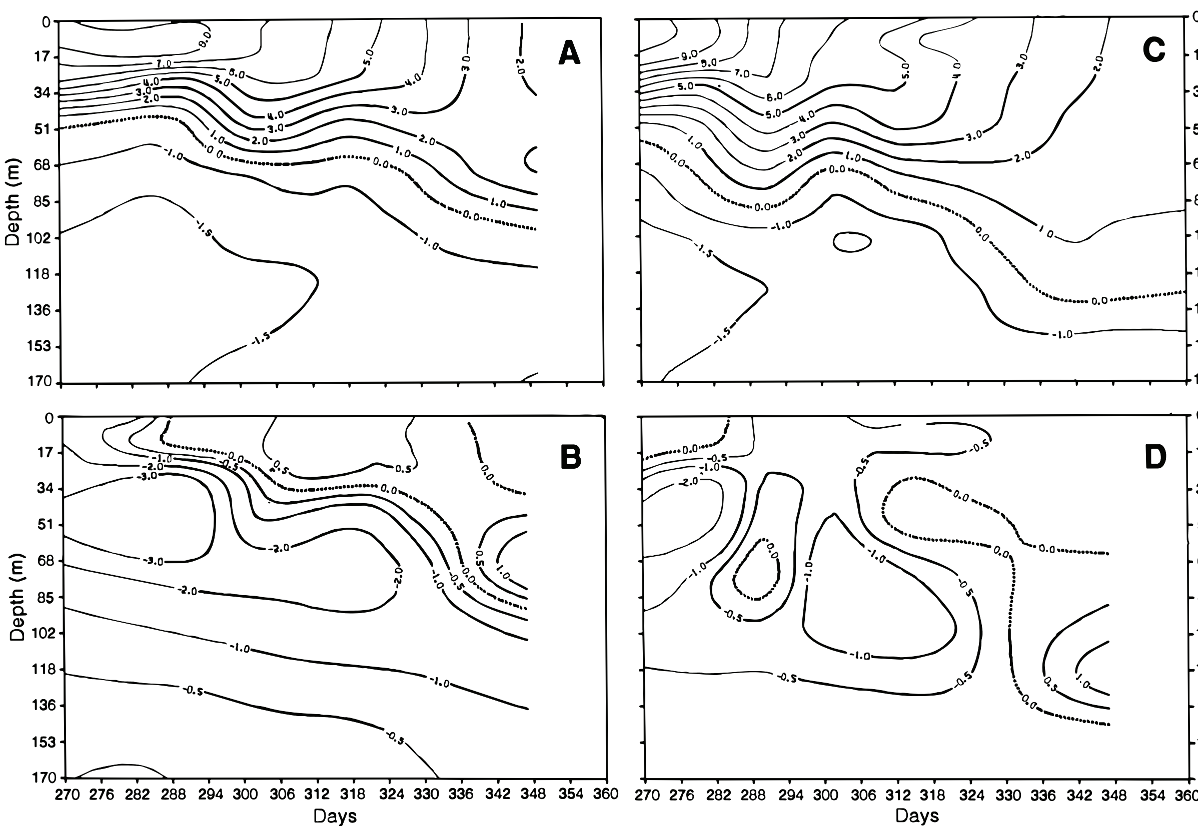


Fig. 5. Time series of (**A**) temperature and (**B**) anomaly *versus* depth at Station 27 for the autumn of 1991, and time series of (**C**) temperature and (**D**) anomaly *versus* depth at Station 27 for the autumn of 1992.

all data collected on the station since 1946. The position of this station is such that the cold water (< 0.0°C) that forms the CIL is present year around in water depths from about 100 m to the bottom. Hence this time series is invaluable in monitoring the variability in the seasonal upper layer as well as the core of the CIL, however, it does not show the full vertical extent of the CIL over the continental shelf. A significant portion of the interannual variance in the temperature at Station 27 is accounted for by the wind and local air temperature (Petrie *et al.*, 1992). They were able to predict, using regression analysis of water on air temperature from 1963 to 1986, the water temperatures at Station 27 for the period 1987 to 1992 with reasonable agreement with observed values.

The 1991 time series showed the upper layer temperatures ranging from 2° to 7°C during the annual autumn survey with temperature anomalies slightly above average. The time series also showed a cooling rate in the upper layer of approximately 0.1°C/day from mid-October to mid-December. At depths greater than 60 to 80 m, the temperature remained below 0.0°C with negative anomalies ranging from -0.5° to -2.0°C in 1991. The 1992 data showed slightly lower upper layer temperatures than in 1991 for the same time period, while again at deeper depths the temperature remained below 0.0°C with negative anomalies up to -1.0°C until early-December when the anomalies became positive. The average bottom (175 m) temperature anomaly from October to December was about -0.5°C in 1991 and had warmed to -0.2°C in 1992.

A comparison of Fig. 3 and 5 showed some differences in the magnitude of the temperature anomaly during the autumn of 1991 at Station 27 and the Bonavista transect. For example, at depths below 50 m at Station 27 the average anomaly over the autumn period was about -1.0° to -2.0°C, while in the inshore regions of the Bonavista transect the anomaly was about -0.5°C in deep water. Some of these differences may be accounted for by the difference in the averaging interval from which the anomaly was calculated; 1981 to 1990 for Bonavista and 1946 to 1992 for Station 27.

Bottom temperatures

Figure 6 shows a location map of the 1992

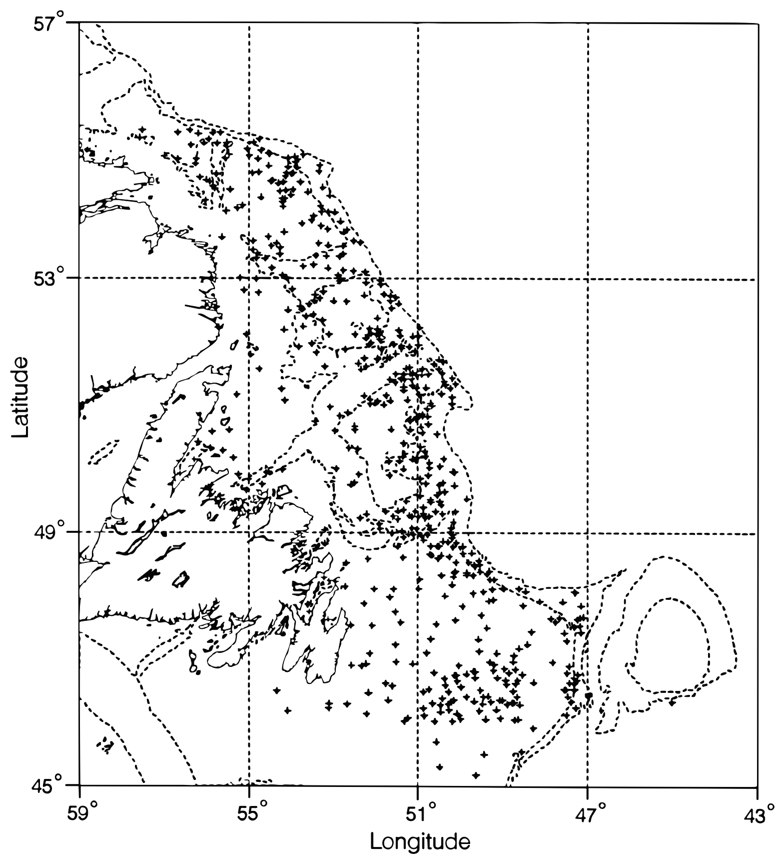


Fig. 6. Location map showing set positions during the 1992 annual autumn groundfish survey.

annual groundfish survey in Div. 2J and 3KL. This survey began in 1977 in Div. 2J, 1978 in Div. 2J and 3K and in 1981 over Div. 2J and 3KL. The average (1980–90) bottom temperature corresponding to these surveys is shown in Fig. 7. The average bottom temperature over the northeast Newfoundland shelf (Div. 2J and 3K) ranged from 0.0°C inshore, to 4.0°C offshore at the shelf break. The average temperature over most of the Grand Bank varied from -1.0° to 0.0°C, and to 4.0°C at the shelf break. In general the isotherms followed the bathymetry exhibiting east-west gradients over most of the northeast shelf. Figure 8 show bottom temperature and anomaly maps from 1980 to 1990. In general bottom temperatures were at or above the mean during 1981/82 and from 1986 to 1989, and below average from 1983 to 1985 and from 1990 to 1992, over most of the Div. 2J and 3KL area. The years 1984 and 1986 were the two extremes with anomalies up to -1.0°C in 1984 and up to 1.0°C in 1986 over most of the northeast Newfoundland shelf.

The percentage area of water at temperatures less than -1.0°C on the Grand Bank in 1992 was less than in 1991, but still significantly larger than the 1980–90 mean. In 1991 the temperature was about average over the northeast shelf, while over the northern Grand Bank (Div. 3L) the anomaly ranged from -0.25° to -1.0°C. In 1992 the temperature anomaly ranged from -0.25° to -0.75°C over the northeast shelf and from -0.25° to -1.0°C over the Grand Banks.

Figure 9 shows the boundaries of all strata defined in Div. 3LNO (Doubleday, 1981). Listed in Table 1 and highlighted in Fig. 9 are selected strata for which time series of the bottom temperatures were examined in each division. Strata were selected from inshore outward to the shelf break

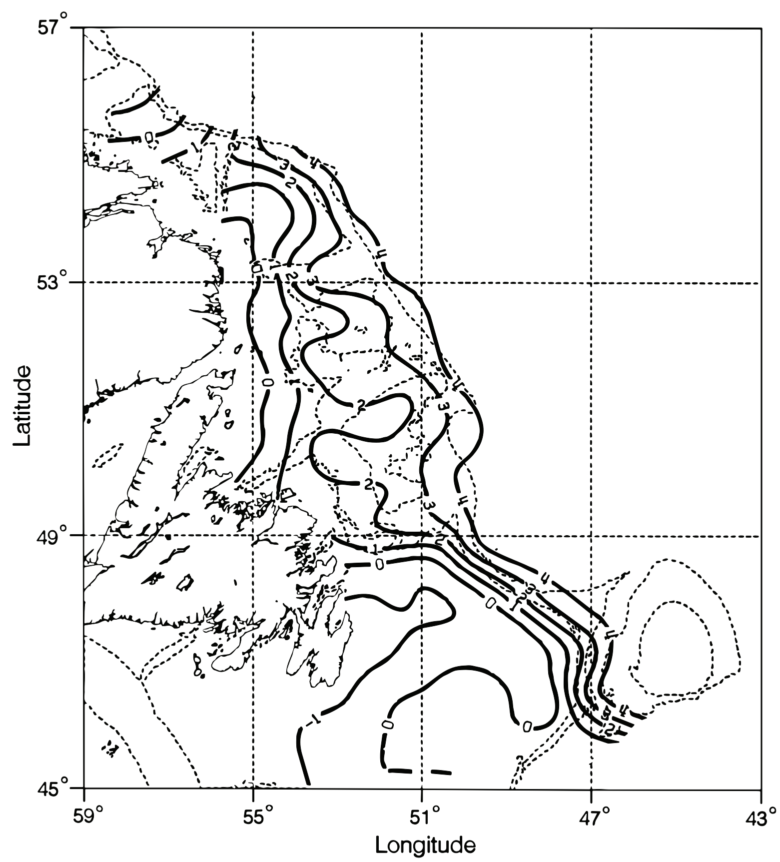


Fig. 7. The 1980–90 average autumn bottom temperature isotherms.

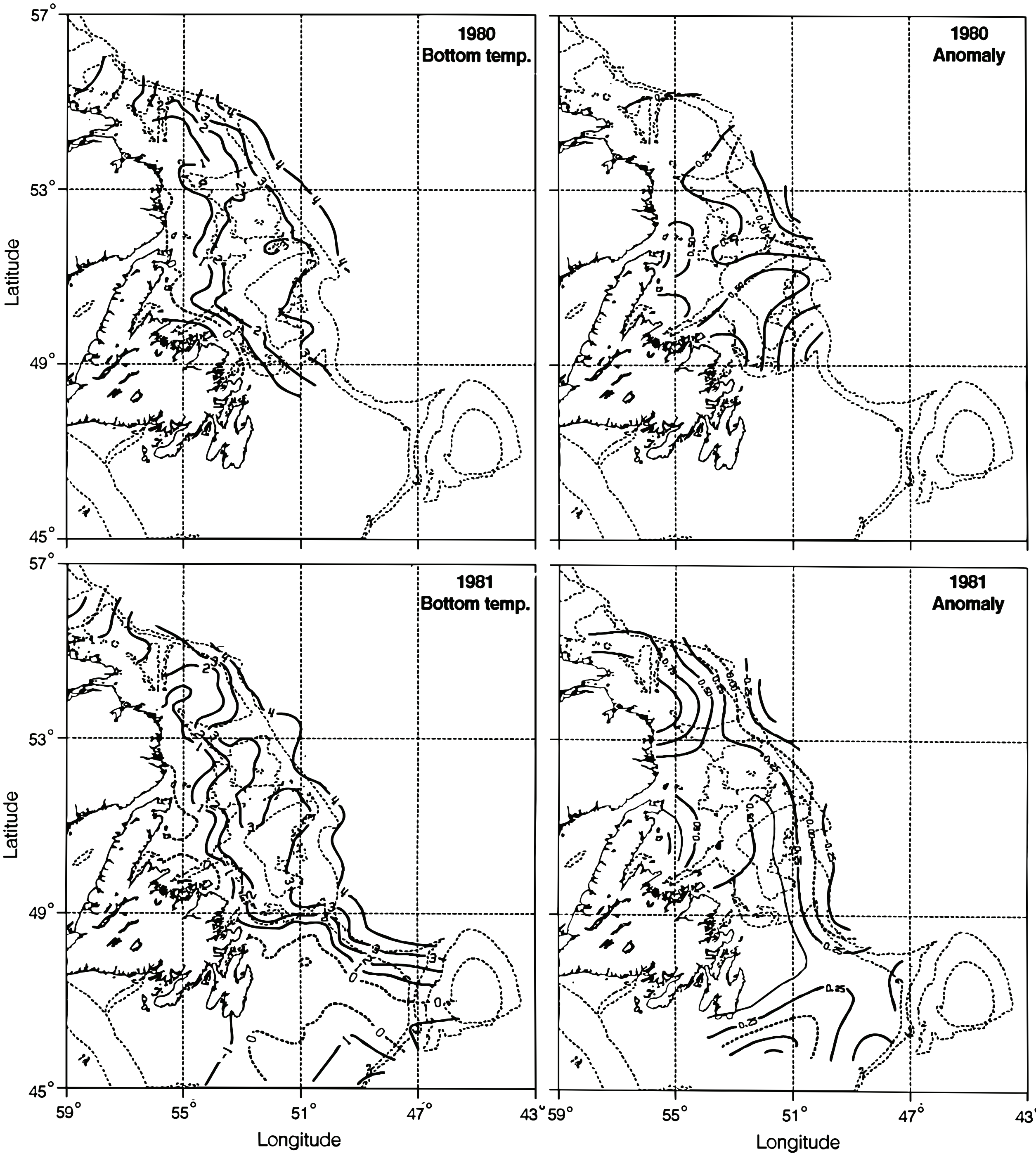


Fig. 8. The 1980 to 1992 autumn bottom temperature isotherms and anomalies.

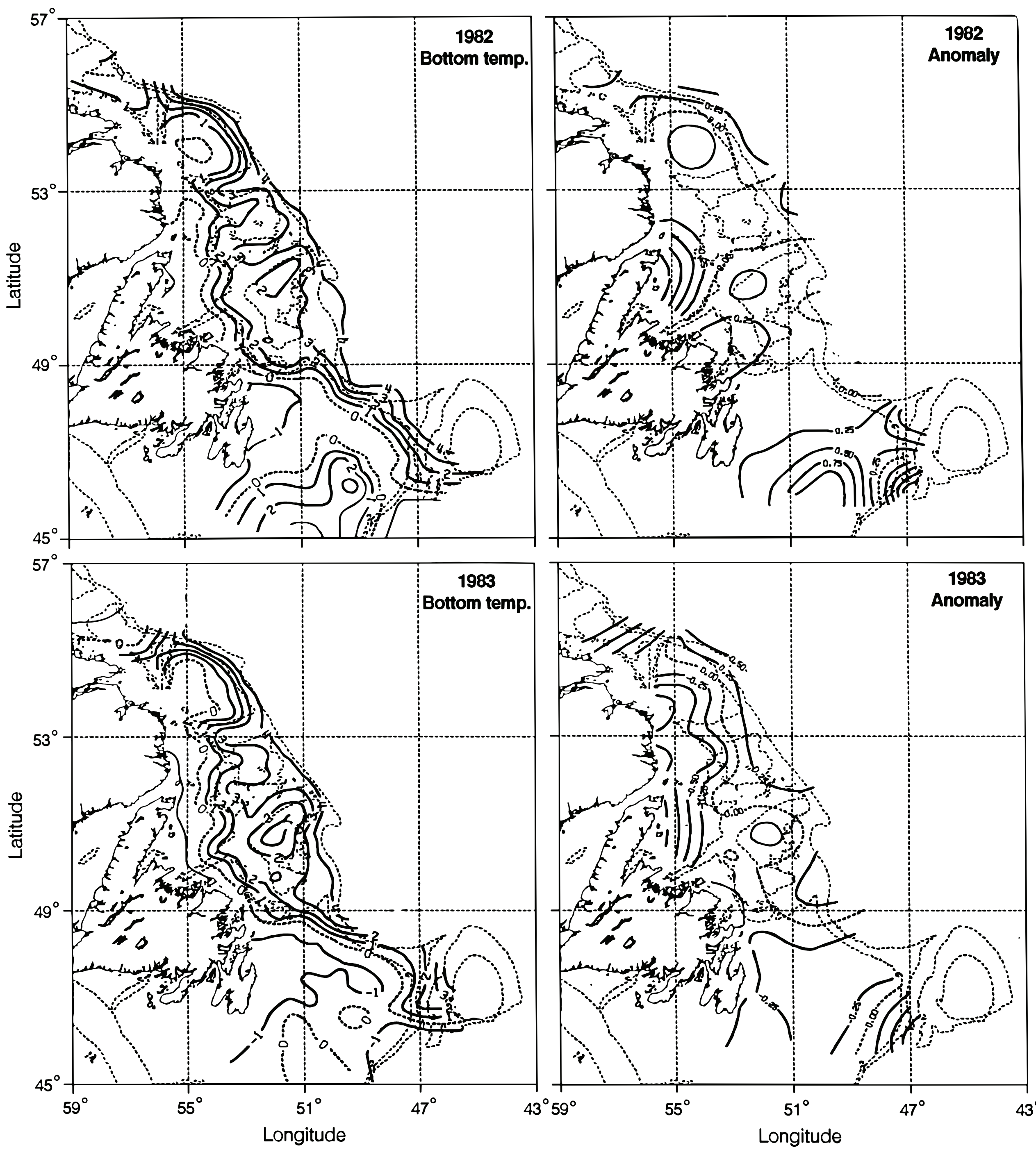


Fig. 8. (Continued). The 1980 to 1992 autumn bottom temperature isotherms and anomalies.

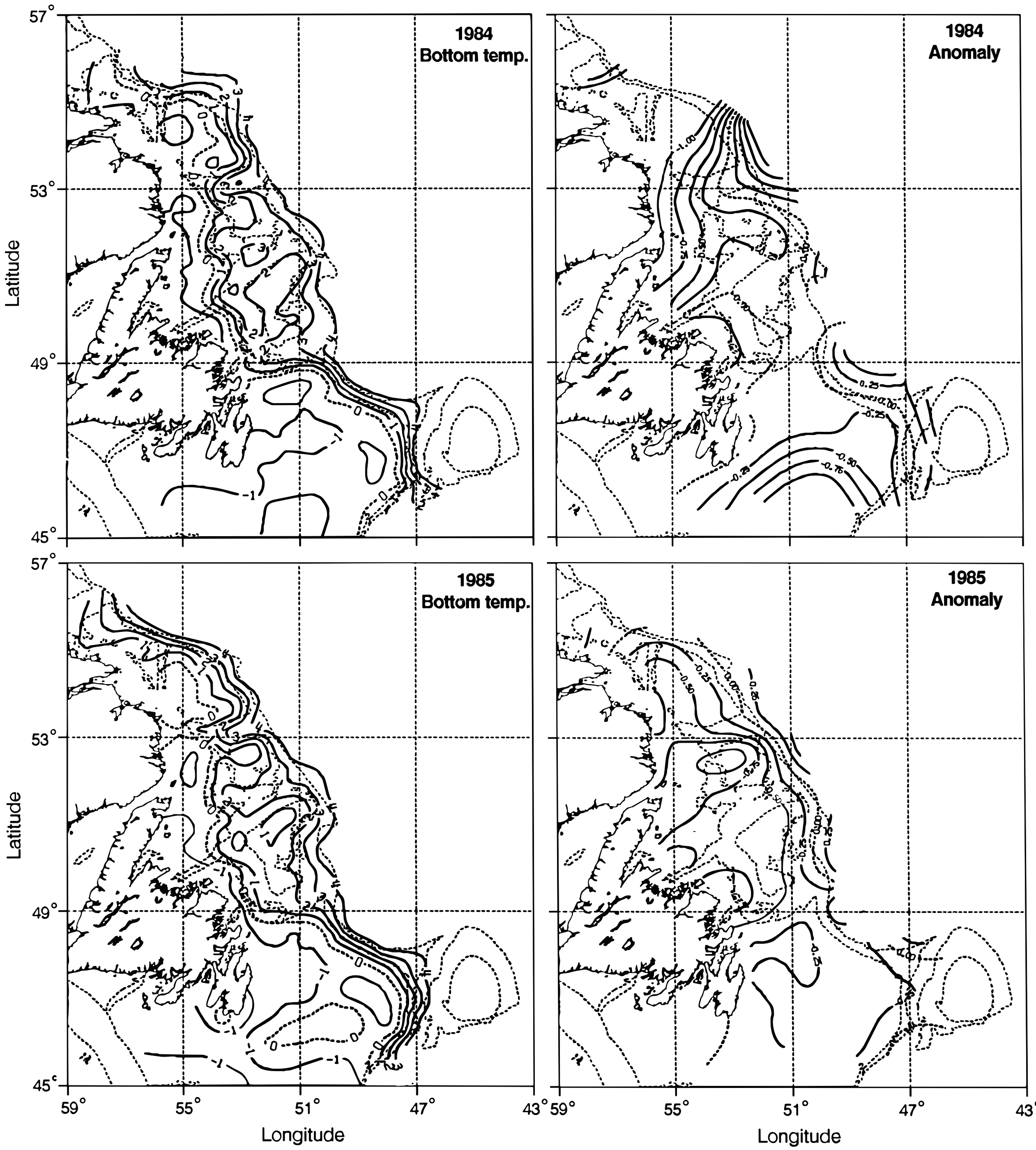
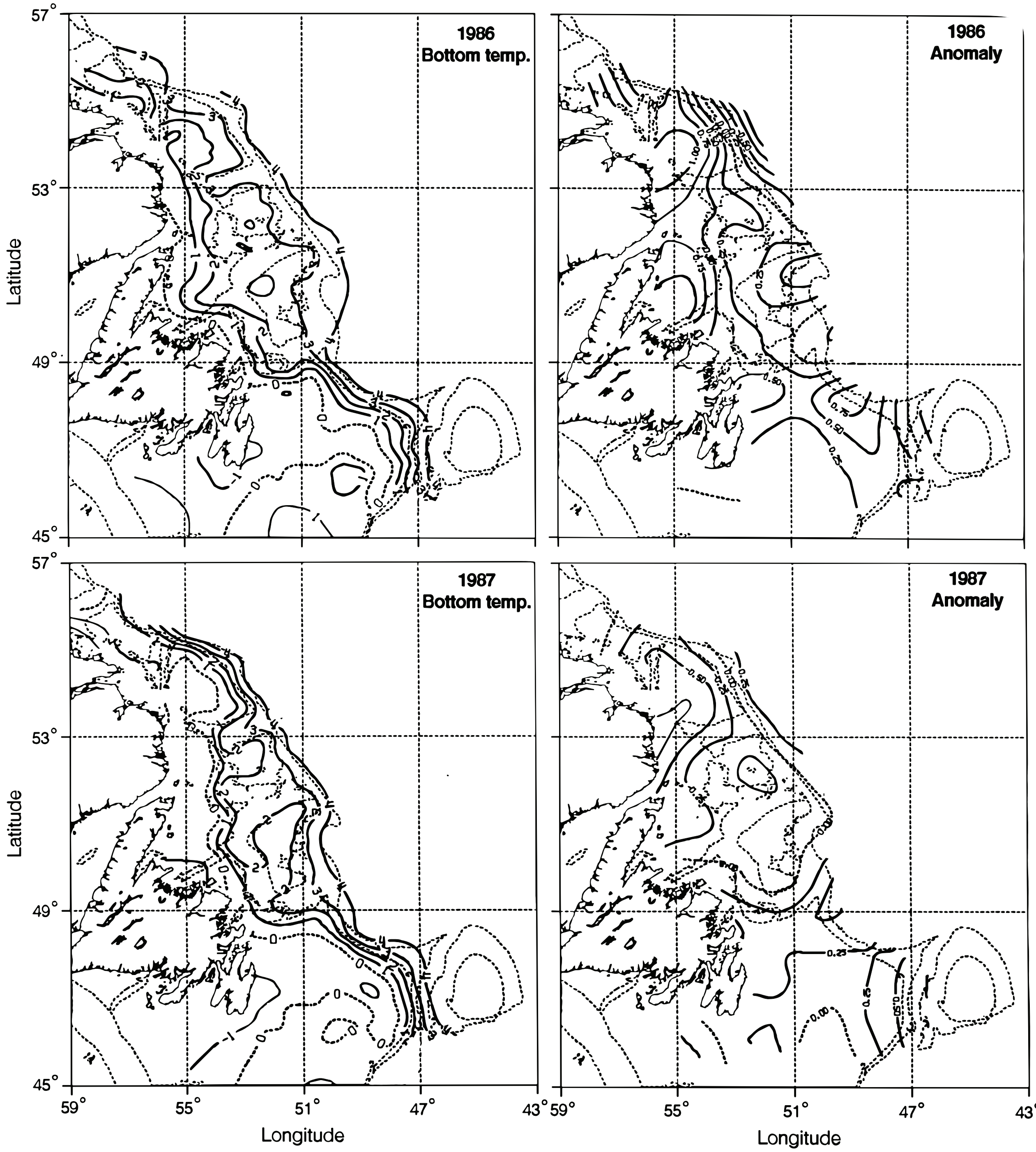


Fig. 8. (Continued). The 1980 to 1992 autumn bottom temperature isotherms and anomalies.



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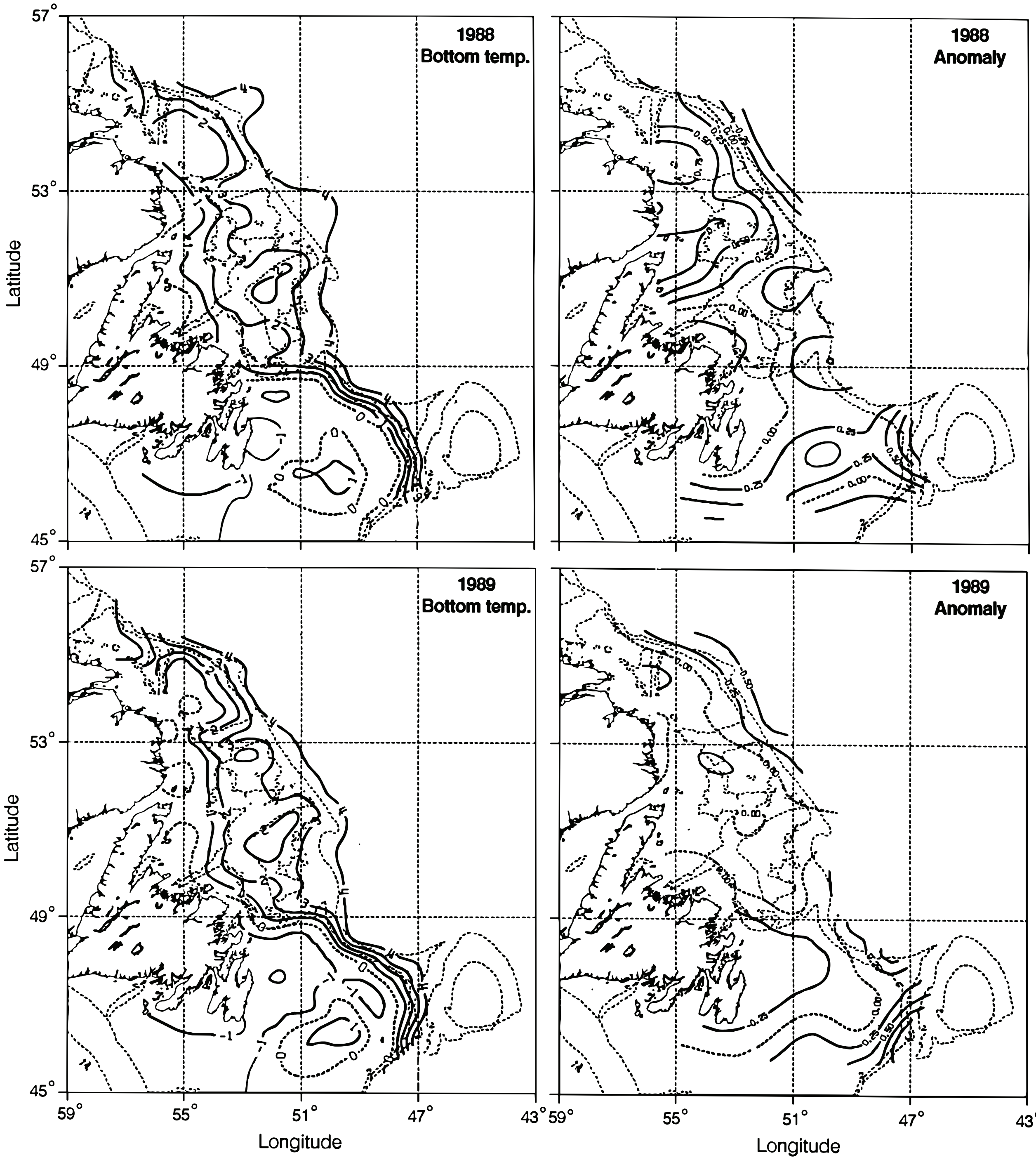

Fig. 8. (Continued). The 1980 to 1992 autumn bottom temperature isotherms and anomalies.

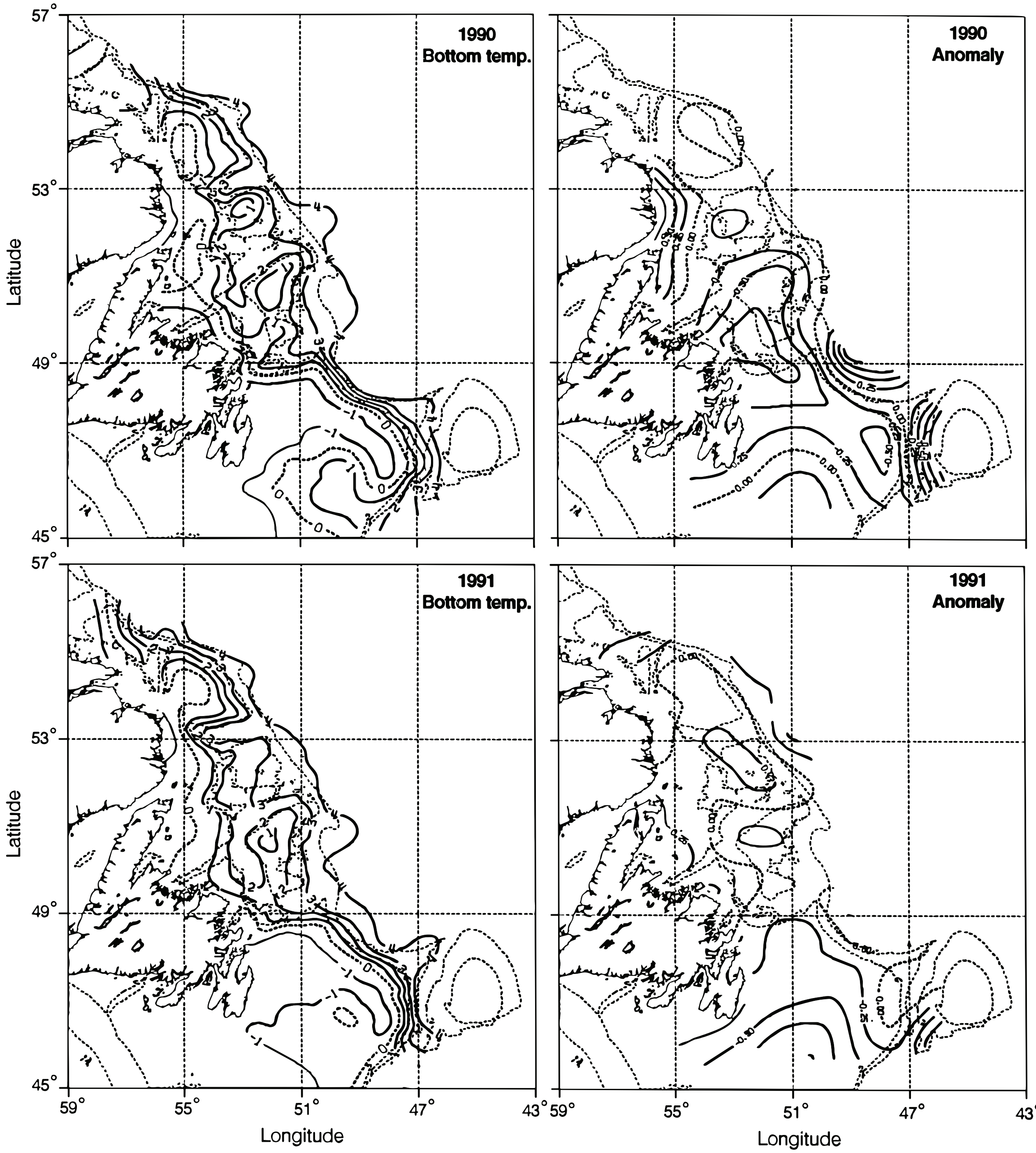

Fig. 8. (Continued). The 1980 to 1992 autumn bottom temperature isotherms and anomalies.

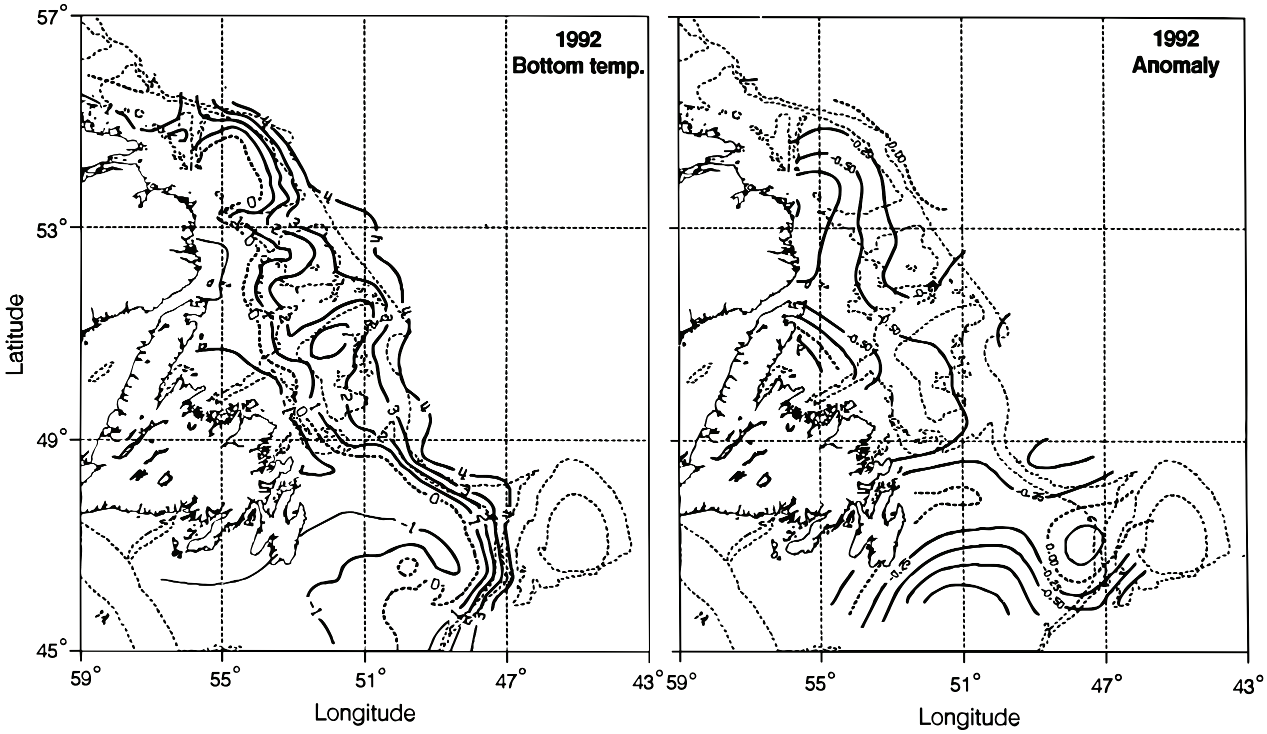

Fig. 8. (Continued). The 1980 to 1992 autumn bottom temperature isotherms and anomalies.

TABLE 1. Analysis of various strata in NAFO Div. 2J and 3KL.

Division	Stratum. No.	Depth Interval (m)
2J	205	101–200
	206	101–200
	213	201–300
	222	301–400
	223	401–500
	224	501–750
	236	751–1 000
3K	620	201–300
	625	301–400
	631	401–500
	630	301–400
	634	201–300
	633	301–400
	645	401–500
	646	501–750
	647	751–1 000
3L	341	93–185
	350	57–92
	372	57–92
	372	57–92
	384	57–92
	390	93–185
	391	184–275
	392	276–366
	729	367–549

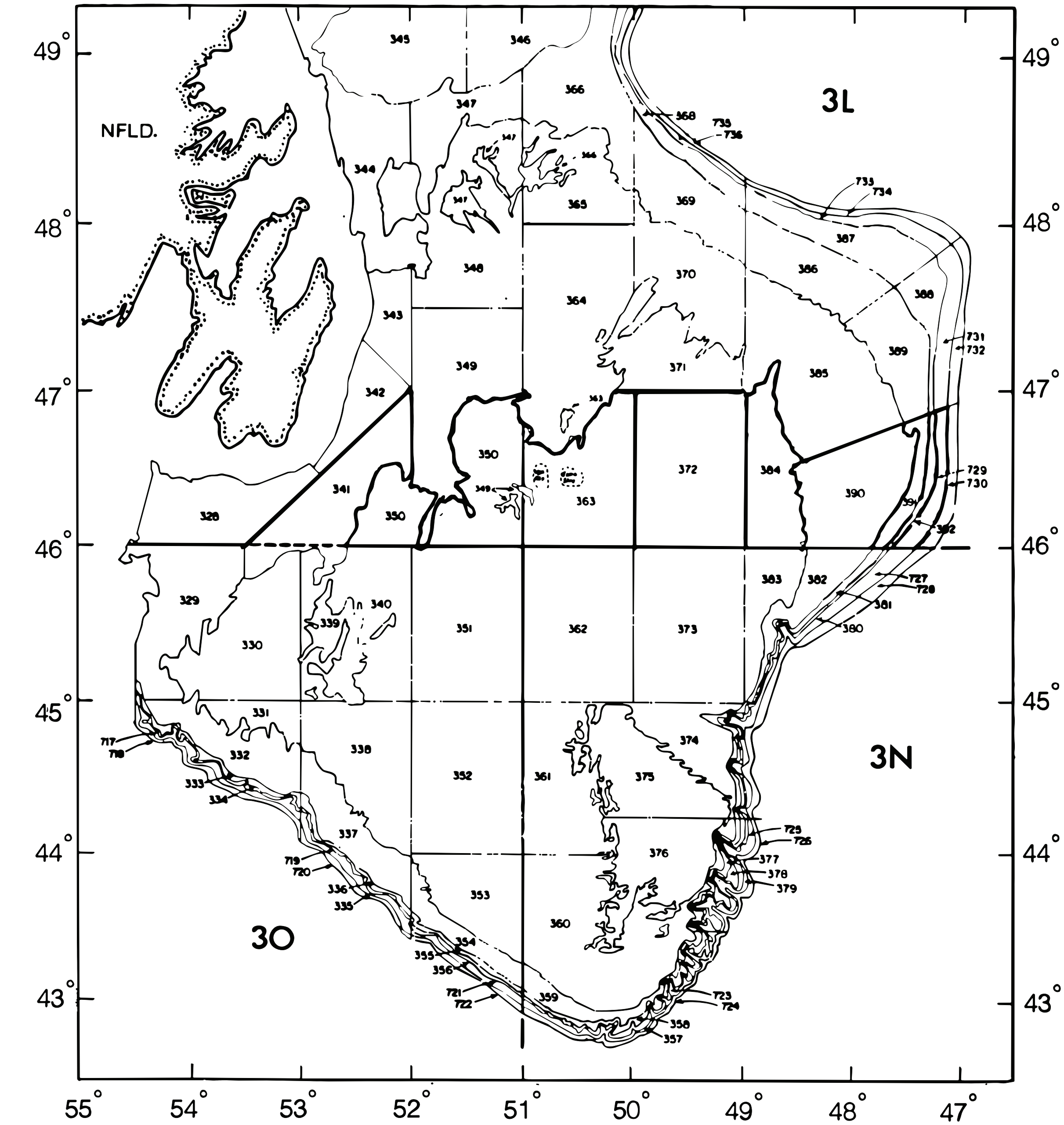

Fig. 9. Strata in NAFO Div. 3LNO.

spanning all depth ranges for each division. As described earlier, bottom temperatures for all sets in each stratum were averaged for each year.

Time series plots of average bottom temperature and anomaly for each year (for the autumn survey) for the selected strata in Div. 3L since 1981 are shown in Fig. 10. The temperatures ranged from -1.0° to 4.0°C over water depths from 93 to 549 m. The time series showed a consistent negative anomaly from about 1983 to 1986 with maximum amplitude of about -1.2°C. A negative anomaly starting in 1990 (with maximum amplitude of about -1.5°C) extended over most of the shallow portion of the Grand Bank. Offshore of stratum 390, in deeper water, the anomaly was positive reaching a maximum of 1.0°C.

Figures 11 and 12 show the location and average bottom temperatures and anomalies for selected

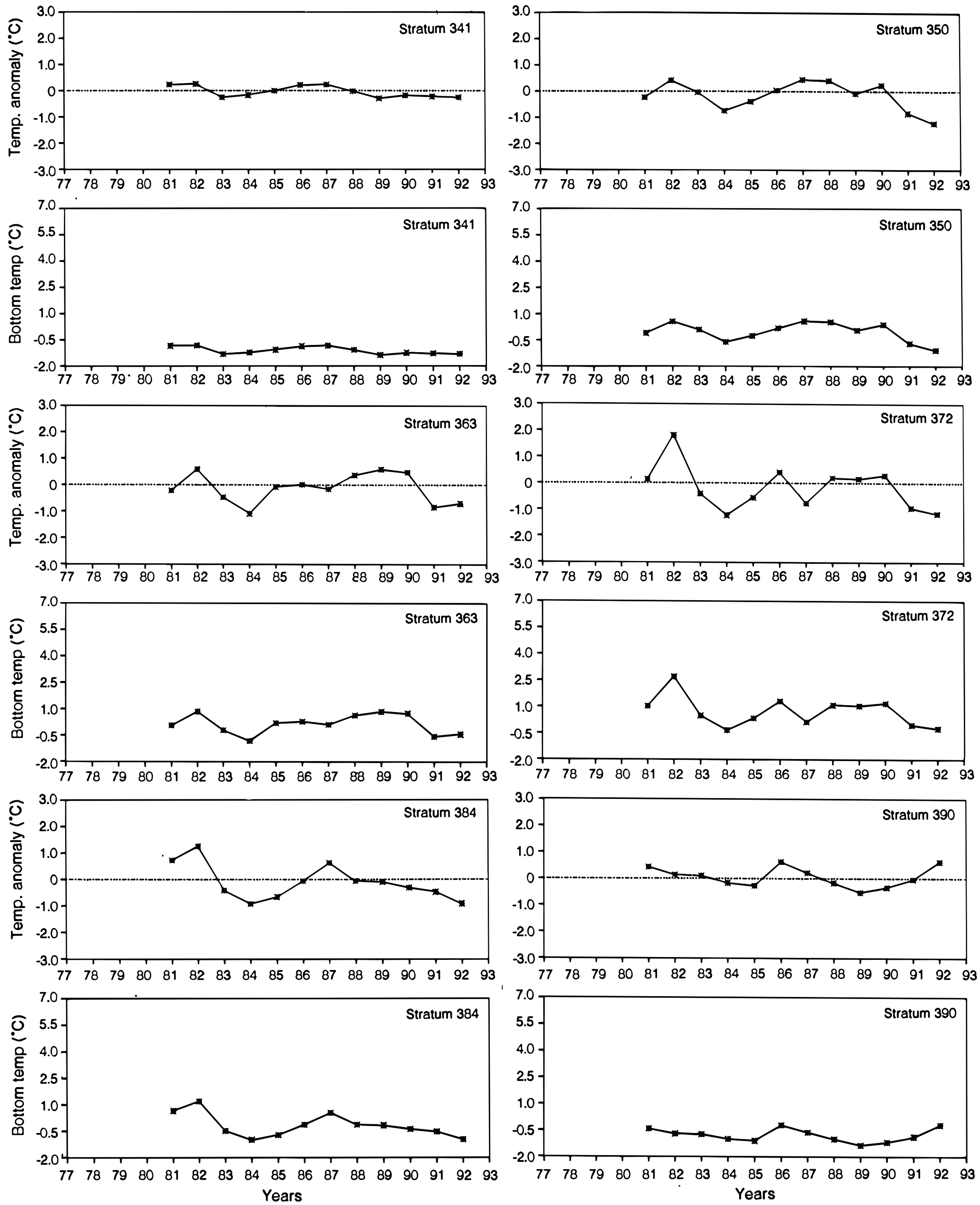

Fig. 10. Time series of bottom temperatures for selected strata (Table 1) in NAFO Div. 3L.

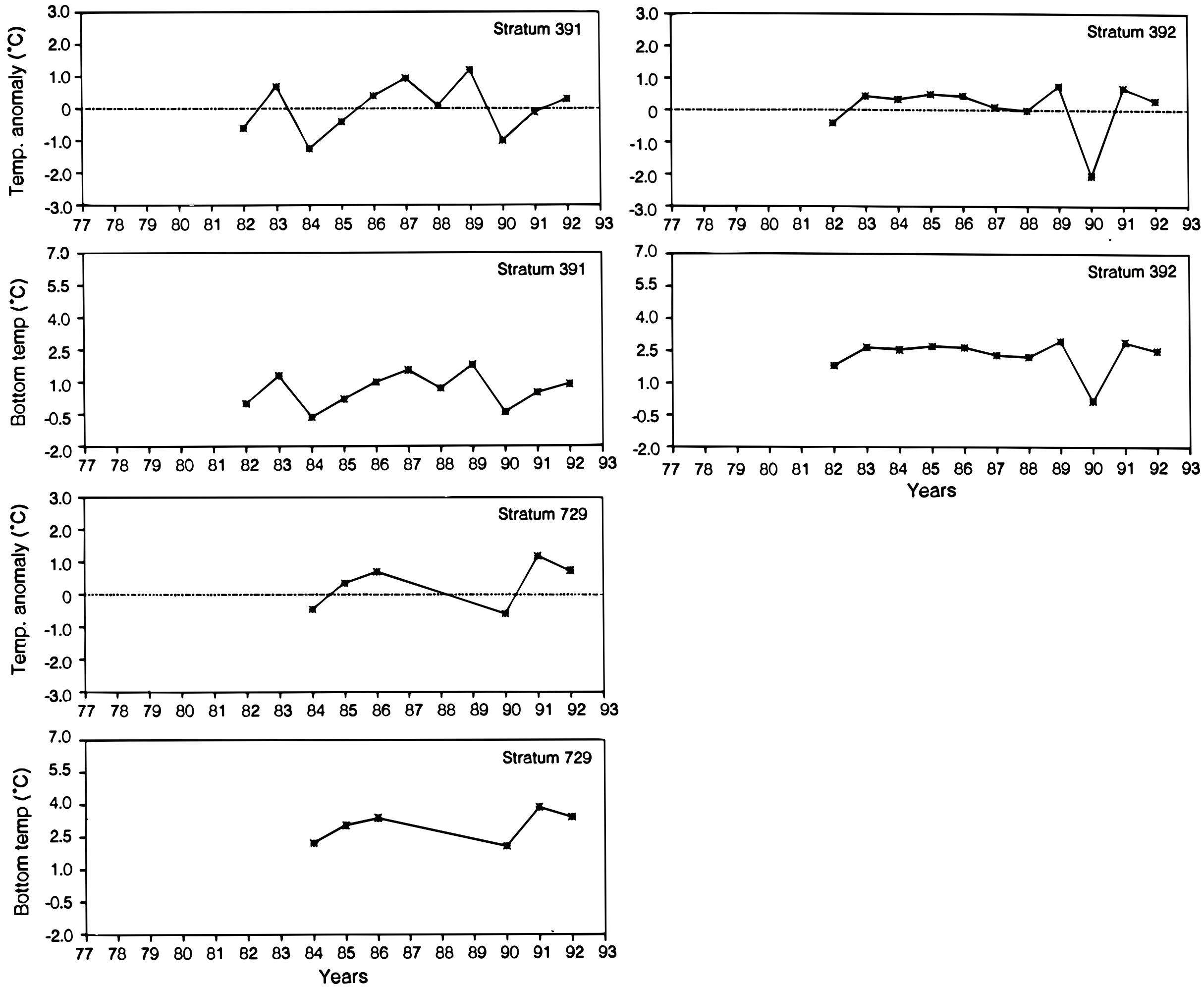

Fig. 10. (Continued). Time series of bottom temperatures for selected strata (Table 1) in NAFO Div. 3L.

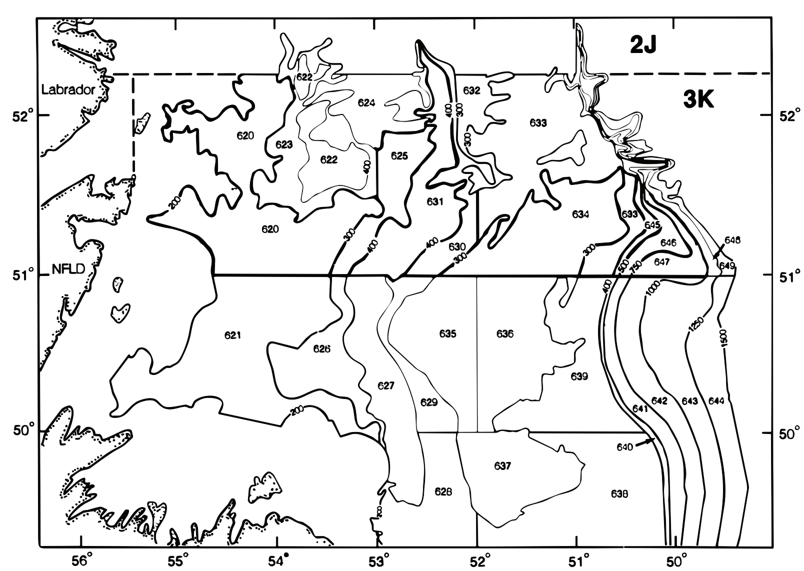

Fig. 11. Strata in NAFO Div. 3K.

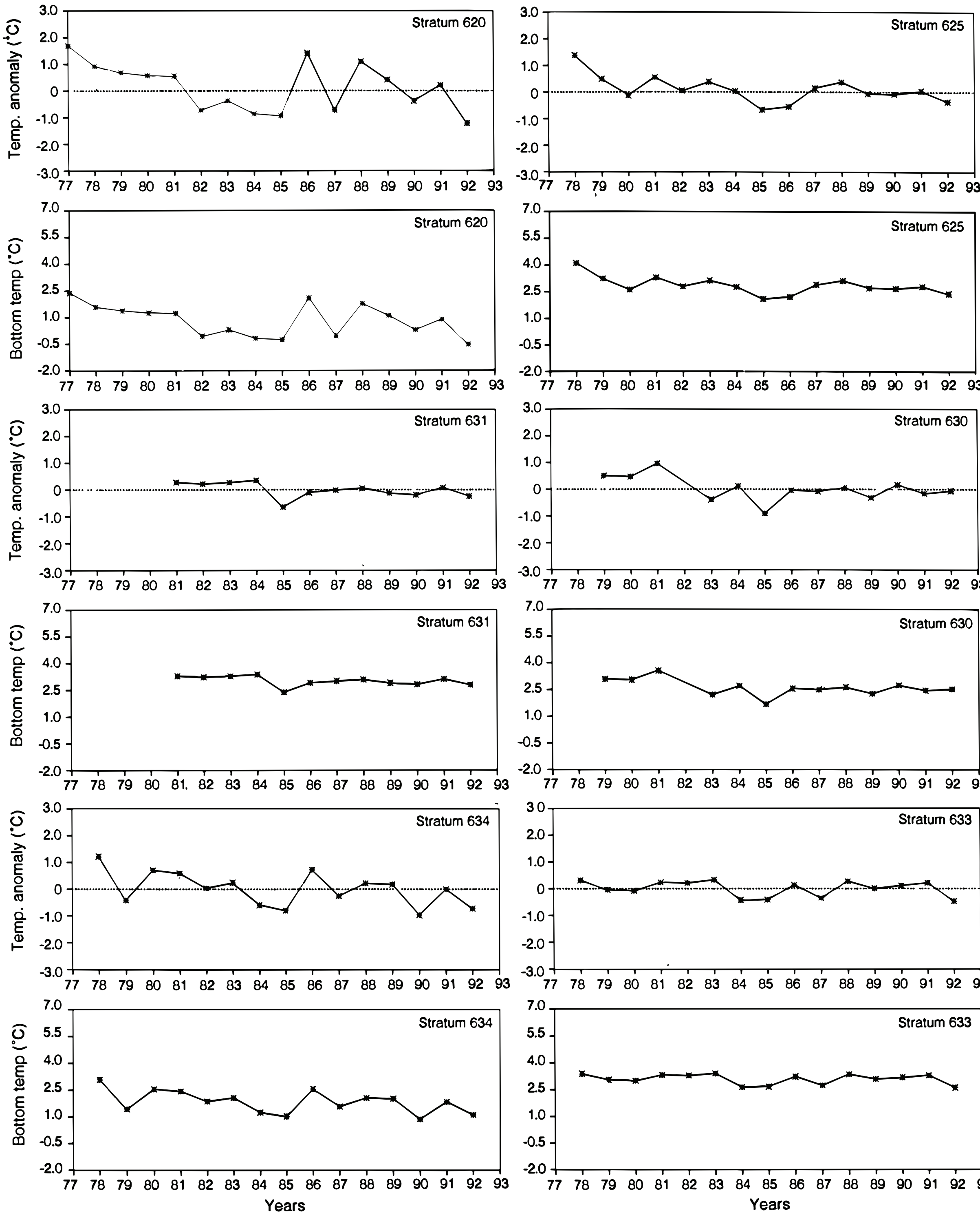

Fig. 12. Time series of bottom temperatures for selected strata (Table 1) in NAFO Div. 3K.

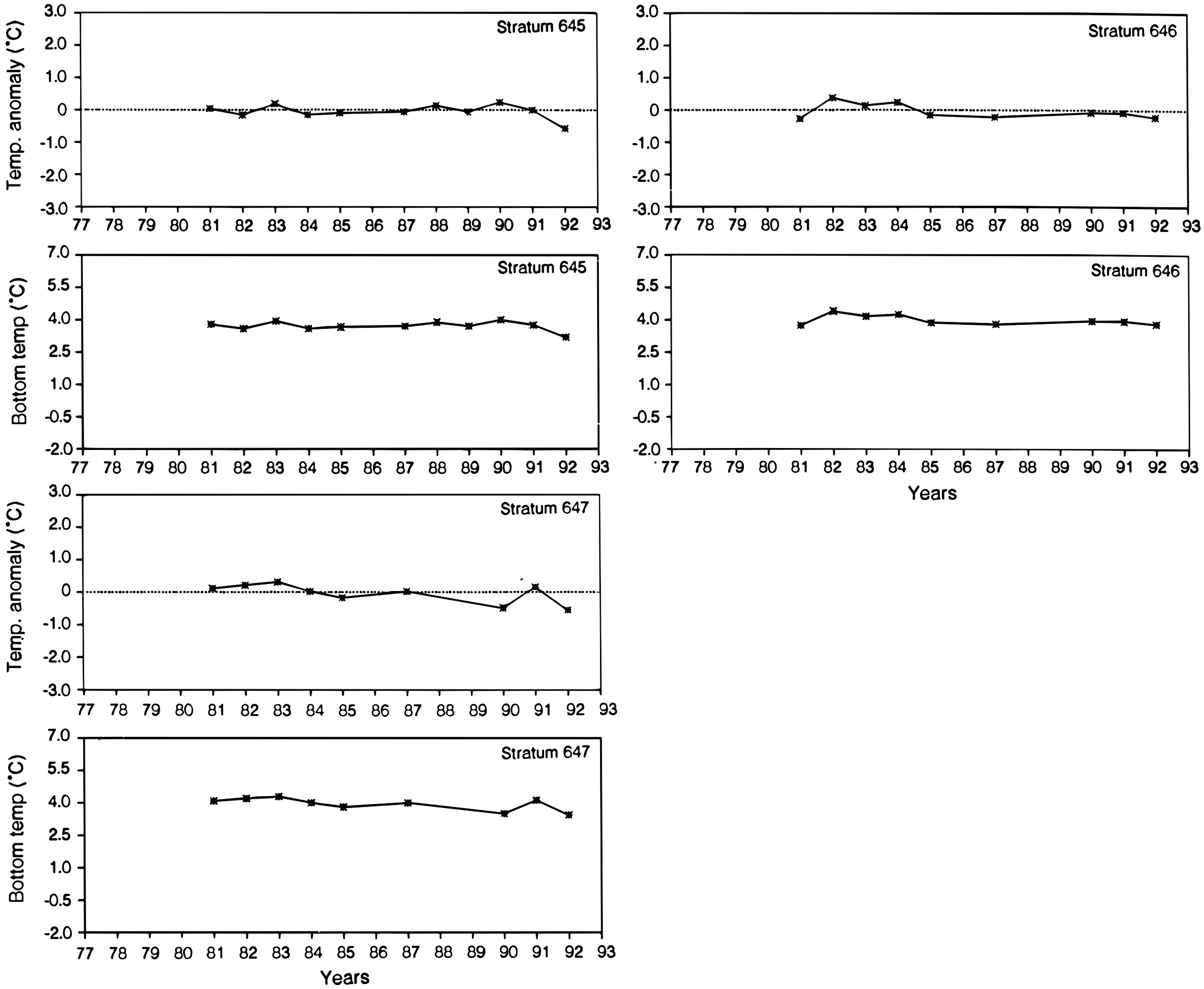

Fig. 12. (Continued). Time series of bottom temperatures for selected strata (Table 1) in NAFO Div. 3K.

strata in Div. 3K. The temperature ranged from 0.5° to 4.0°C over water depths of 200 to 1 000 m. A negative anomaly existed over most of the area in 1984/85 and again in 1992 reaching a maximum of -1.2°C. The positive anomaly in the deeper waters of Div. 3L was not apparent in Div. 3K. Similarly Fig. 13 and 14 show location and average bottom temperatures for the selected strata spanning all depth intervals in Div. 2J. Again there were significant negative anomalies during 1984/85, and in 1992 ranging from 0.0° to -1.0°C. Temperatures generally ranged from -1.0° to 4.0°C in water depths of 100 to 1 000 m.

In general the time series plots of the average bottom temperature data within a particular stratum, with a few exceptions, showed a high degree of variability from one year to the next. For example the time series for stratum 341 near the edge of the Avalon Channel showed only weak anomalies during 1984/85 and 1991/92, unlike most other strata in Div. 3L. No attempt was made to examine individual data points within each stratum for each year. It is expected that there may be high variations in the data due to strong temperature gradients over depth intervals up to 400 m for some strata.

Summary

The analyses presented in this paper show a large upper layer temperature anomaly in the autumn of 1992 and near normal values in 1991. This together with below normal air temperatures (-6° to -10°C below the mean in early February, Saulesleja, 1993) during the winter of 1992/93 had resulted in near record ice coverage south of 46°N latitude by

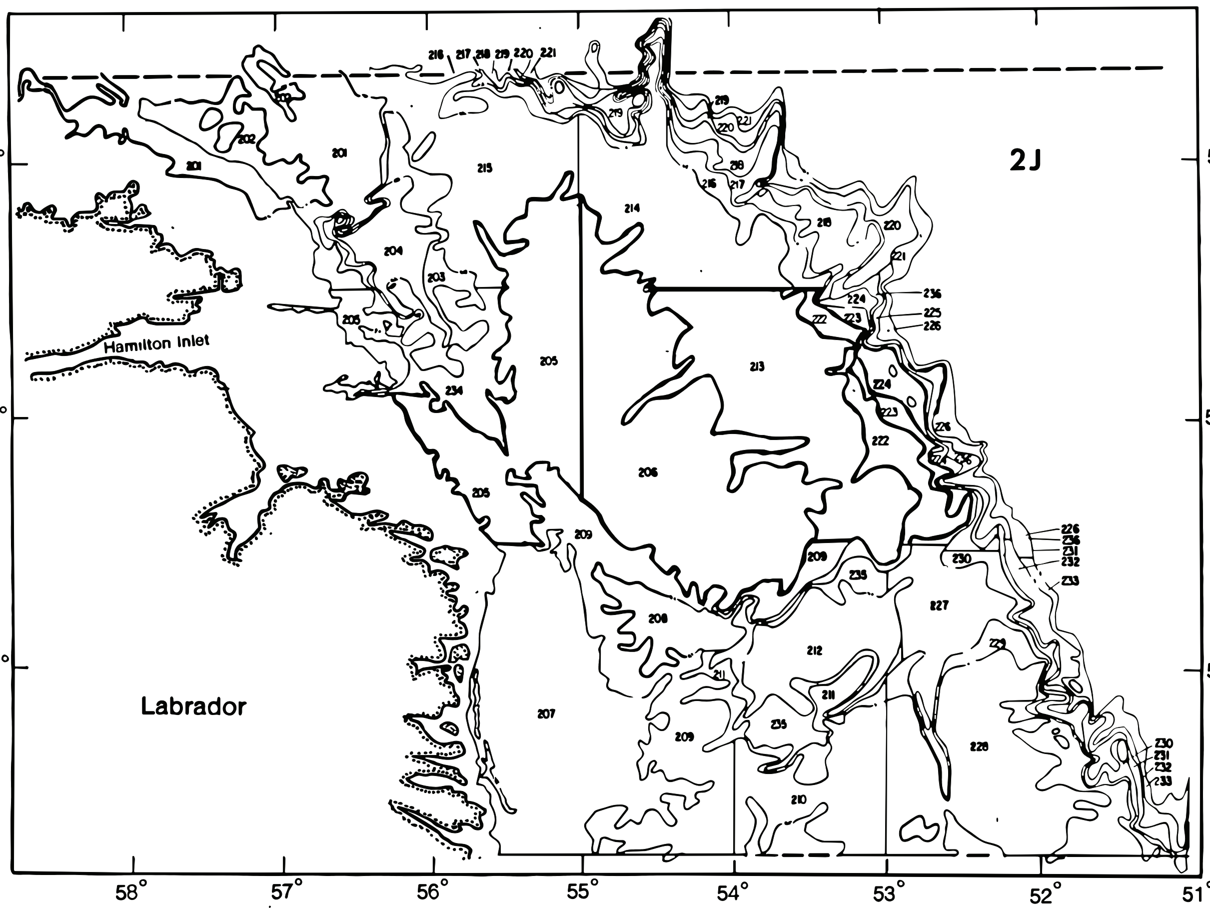

Fig. 13. Strata in NAFO Div. 2J.

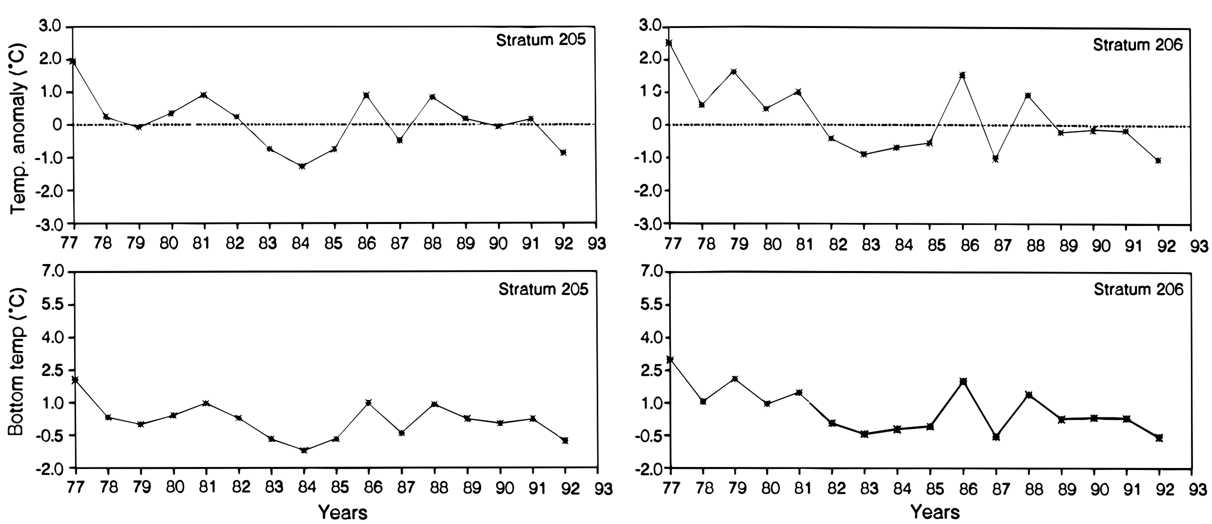

Fig. 14. Time series of bottom temperatures for selected strata (Table 1), and strata 236 in NAFO Div. 2J.

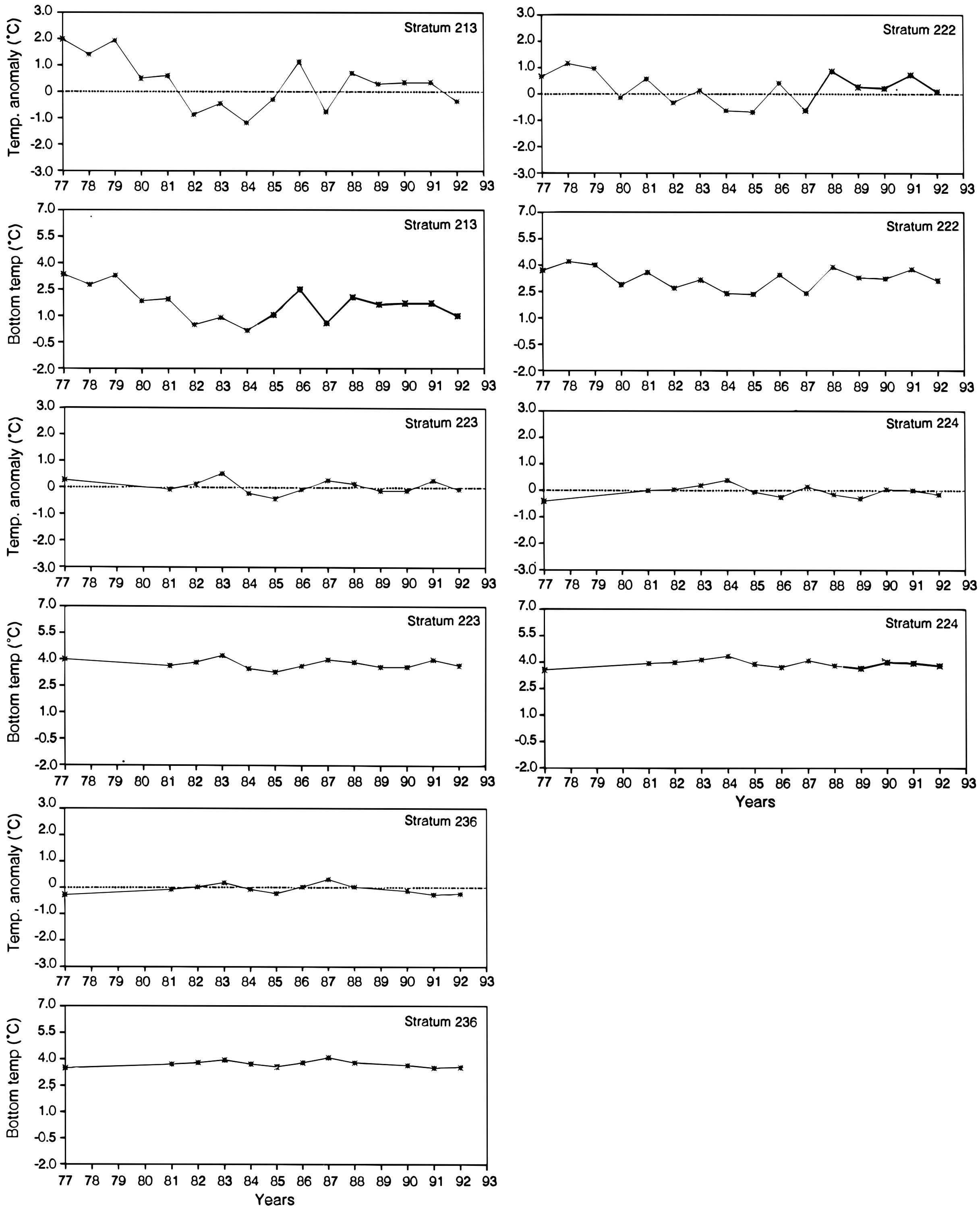

Fig. 14. (Continued). Time series of bottom temperatures for selected strata (Table 1), and strata 236 in NAFO Div. 2J.

early February 1993. The strong negative temperature anomalies experienced during the spring and summer of 1991 had disappeared by the autumn of 1991 over most areas. The cross-sectional area of the CIL across the northeast shelf was less than the 1981–90 mean in 1991 and slightly greater in 1992. In addition the upper layer along the transect was significantly colder in 1992 compared to 1991 and the long-term mean.

At Station 27 temperature anomalies were slightly positive in the upper layer in 1991, and slightly negative in 1992, and strongly negative in both years at mid-depths except towards the end of the autumn survey. The analysis showed some differences in the anomalies seen near shore at Cape Bonavista and at Station 27. This may have been due to differences in the temporal averaging or the spatial separation in the two locations (about 150 km).

Bottom temperatures anomalies were restricted to the southern areas of Div. 3L in the autumn of 1991, but appeared to be more wide spread in the autumn of 1992. Analysis of bottom temperature time-series data by strata showed negative anomalies during 1984/85 and 1991/92 for some but not all strata. Variations in the set positions within the strata together with temporal aliasing between years make a more detailed analysis of the data necessary.

Acknowledgements

I extend thanks to D. Senciall for computer software support and D. Foote for data processing and technical assistance in the preparation of this document. I also thank the scientist in the Groundfish Division at the NAFC, for collecting and providing much of the data contained in this study.

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